Wavelength Striped Semi-synchronous Optical Local Area Networks

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Abstract: We present a local area sub-network design avoiding optical buffering, bit level synchronization and regeneration. Using currently available components we calculate acceptable utilisation when scalability is limited to local, system, storage and desk area networks. The architecture draws upon well-understood computer networking concepts, and uses wavelength striping of the packets as a method of achieving low latency and high capacity for use in the target systems.

1 Introduction

Improvements in the capabilities, cost and availability of photonic components and transmission systems delivering low cost components are well matched to local data-communications applications. Although researchers have investigated techniques such as Optical Burst Switching and Optical Packet Switching, major hurdles remain in the realization of a complete system. In order to achieve optical packet switching with currently available components with a reasonably simple and low cost implementation suitable for applications in computing networks, we propose a wavelength striped semi-synchronous local area optical network [1].

We assume that at network boundaries, issues concerning security, trust, classification, QoS, etc which require significant computing power remain electronic. Taking a local area network focus allows acceptably high utilization in the optical data-path without the need for optical buffering, limits problems due to dispersion and non-linearities, and obviates the need for inband processing of data within the network.

2. Wavelength striping

In a wavelength striped format (also called 'optical bus' [2] or 'bit parallel WDM' [3]) capacity is increased by simultaneously launching parallel pulses on different wavelengths (e.g. a bit from each wavelength channel is launched at the same time). This technique is particularly suitable for computer interconnects and high speed parallel systems where the requirement is for high data rates to a single end user. Wavelength striping could also offer advantages for novel coding techniques and potentially avoid serial to parallel, parallel to serial conversion.

Previous wavelength striped research has focused on networks with moderately long fibre lengths and used bit error rate (BER) as the impairment criteria, whereas we focus on the local area network and effects causing timing errors. Whereas most previous work has sought to compensate for or eliminate the delays our goal is to determine the maximum delay encountered by a bit during transmission and optimize for network efficiency as much as possible by choice of components and packet format.

3. Slot format

The original LAN technologies all held packets in end-systems until transmission was (believed) to have been successful. They could be categorized as either synchronous or asynchronous. In the synchronous ones, nodes in the network received a continuous signal from the communications media to which they synchronized their transmissions at the bit level, and in which was encoded the information needed to implement Media Access Control (MAC) based on contention avoidance (rings and unidirectional or daisy-chained busses are examples). In the asynchronous ones, such as Ethernet, a receiver would re-synchronize to the bit clock on a per packet basis and the MAC would implement contention resolution.

Un-buffered networks are found in the wireless realm. While local wireless networks often use similar asynchronous access techniques to local wired networks, experience in the wide area led to what can be categorized as semi-synchronous networks – that is synchronized at a time slot level, but asynchronous at the bit level. In these networks, even when fed from a single base-station master clock, the variability in delay (jitter) introduced in radio propagation and/or mobility mean that is simply not possible to ensure that two packets from different sources arrive at the base-station (or satellite) with the required sub-bit timing accuracy to run synchronously.

Drawing on this previous work, we consider a semi-synchronous optical network composed of point-to-point links and a central switch. The control channel is synchronised fixed time slots for packet transmission, within the slot a suitably chosen guard time avoids bit loss, while the receiver node recovers the data at the bit level.

4. Control channel

The switch communicates slot timing and phase information to each of the network nodes so that the transmitters can lock onto the switch slot structure.

This bi-directional control channel, on a separate wavelength which can be at a lower data rate, is also used as the request / grant channel to implement the MAC. As with wireless communications we can consider MAC layers implementing reservation and contention mechanisms. When granted access to a time slot a node can transmit using wavelength striping on the data channels, $?_{1..n}$, which are routed through the optical switch to the designated destination.

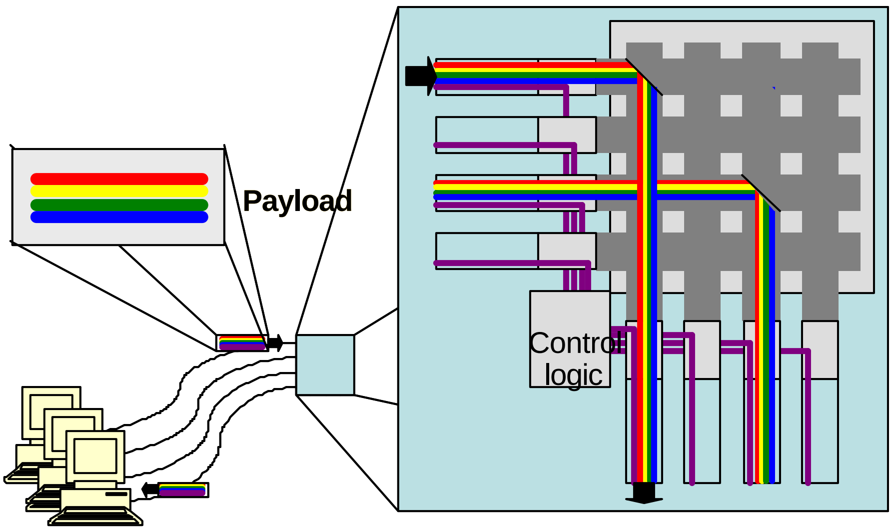

Figure 1. Schematic of the network showing wavelength striping and control channel

5. Bit delay, guard band and network efficiency

In the wavelength striped format a limiting factor is bit skew due to group velocity dispersion in the fibre. This is the aspect that most previous work has focused on. We must, however, also ensure that while the switch is in transition, no packet data is lost. We also must account for delays due to environmental effects such as change in temperature. We therefore, either introduce guard bands, gaps between packets or sacrificial packet preambles.

Presuming bit asynchronous data being transported in a slot sized to take a standard Ethernet frame (12000 bits), to achieve 90% utilisation bit loss due to slip must be less that 1200 bits. At data rates of 10Gbps this would be equivalent to 120ns of bit slip, and at 100Gbps 12ns slip.

If the guard band can be sufficiently short to allow adequate network efficiency, bit level synchronizers are not needed at the switch considerably reducing the complexity of the network. Timing constraints are not as severe although fast clock recovery is required at the receiving node.

To ensure an acceptable delay, high speed (nsec's) optical switches are required. We have chosen high speed SOA based switches which can switch the entire wavelength striped band and are therefore, particularly suitable for this application [4]. Effects causing a determined non varying delay can be compensated for statically. For example, substantial reduction of wavelength skew in the 1550 nm region can be achieved by using dispersion shifted fibre.

Temperature dependant change, fused silica fibre	30ps/km/C
Transmitter jitter	80ps
Slot phase lock accuracy (control channel)	30ps/km/C+80ps
Guard time for optical switch (SOA)	5 ns
Chromatic dispersion at 1550nm standard SMF	1ns/km/50nm
Clock recovery	80ps+few bits

Table 1. Contributions to bit delay

We estimate the worse case delay for given data rates and link distances to determine if these contributions would sum to a guard band using more than 10% of the available data bits. Table 1 lists the most significant contributions to bit delay for a network with links up to 1km and individual wavelengths at bit rates up to 10Gbps. To build a testbed demonstrating the network we keep the data rates compatible with commercially available network interface cards.

Figure 2 shows the worse case bit delay for the conditions in Table 1 with a 10C temperature change and wavelength striping across 50nm. For 4 wavelengths at 10 Gbps each the guard band should be 75 bits. The aggregate bit loss for a packet could be up to 300 bits. This is well within our 1200 bit limit.

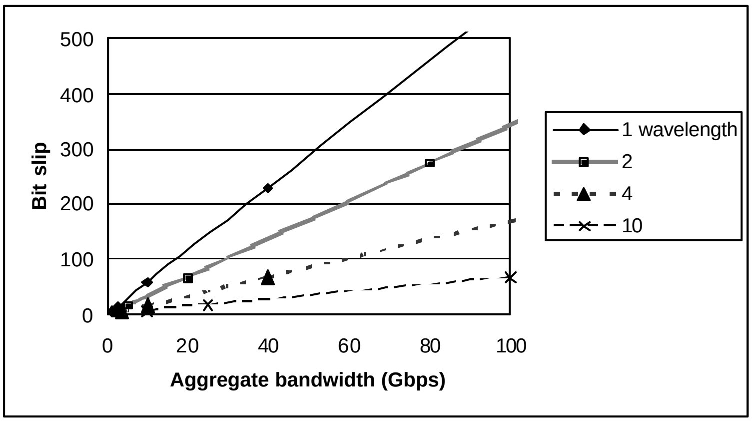

Figure 2. Bit slip per wavelength channel as a function of aggregate bandwidth

6. Conclusions

We have shown that an acceptable level of utilization should be obtained in a wavelength striped semi-synchronous network using high speed SOA based optical switches making this solution a good candidate for local area optical packet networks.

Acknowledgments

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